GEORGIA INSTITUTE OF TECHNOLOGY — OFFICE OF CONTRACT ADMINISTRATION

PROJECT ADMINISTRATION DATA SHEET

[X] ORIGINAL [ ] REVISION NO. ______

Project No. A-57-606 GTRI/~~GIT~~ DATE 8 / 15/ 84

Project Director: A. Sheppard & J. Spurlock School/~~Lab~~ VPR

Sponsor: Whirlpool Corporation

Type Agreement: Standard Industrial Agreement dated 7/11/84

Award Period: From 6/15/84 To 8/31/85 (Performance) 8/31/85 (Reports)

Sponsor Amount:

	This Change	Total to Date
Estimated:	$ 56,374	$ 56,374
Funded:	$ 56,374	$ 56,374

Cost Sharing Amount: $ None Cost Sharing No: N/A

Title: Home Appliance Robotics Research

ADMINISTRATIVE DATA

OCA Contact Brian J. Lindberg X4820

1) Sponsor Technical Contact:

Dr. W. Gale Cutler, Staff V.P.
University Relations
Whirlpool Corporation
The Elisha Gray II Research and
Engineering Center - Monte Road
Benton Harbor, Michigan 49022

2) Sponsor Admin/Contractual Matters:

Dr. W. Gale Cutler, Staff V.P.
University Relations
Whirlpool Corporation
The Elisha Gray II Research and
Engineering Center - Monte Road
Benton Harbor, Michigan 49022

Defense Priority Rating: N/A

Military Security Classification: N/A

(or) Company/Industrial Proprietary: N/A

RESTRICTIONS

See Attached N/A Supplemental Information Sheet for Additional Requirements.

Travel: Foreign travel must have prior approval – Contact OCA in each case. Domestic travel requires sponsor approval where total will exceed greater of $500 or 125% of approved proposal budget category.

Equipment: Title vests with Sponsor. All purchases of special items of equipment in excess of $500 must be approved in writing by Sponsor.

COMMENTS:

Advanced payment of $14,000 received by Check No. 380605 dated 7/24/84

AUG 1984 RECEIVED Research Reports Office

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GTRI
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Project File
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FORM OCA 4:383

GEORGIA INSTITUTE OF TECHNOLOGY OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION/CLOSEOUT SHEET

Date 7/22/86

Project No. A-57-606 School/Lab VPR

Includes Subproject No.(s)

Project Director(s) A. Sheppard & J. Spurlock GTRC / GIT

Sponsor Whirlpool Corporation

Title Home Appliance Robotics Research

Effective Completion Date: 8/31/85 (Performance) 8/31/85 (Reports)

Grant/Contract Closeout Actions Remaining:

- [X] None
- [ ] Final Invoice or Final Fiscal Report
- [ ] Closing Documents
- [ ] Final Report of Inventions
- [ ] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other

Continues Project No. Continued by Project No. A-57-613

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FORM OCA 69.285

n 24-606

Georgia Institute of Technology

A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA

ATLANTA, GEORGIA 30332

OFFICE OF VICE PRESIDENT
FOR RESEARCH

December 10, 1984

Dr. W. Gale Cutler
Staff Vice President
University Relations
Whirlpool Corporation
Monte Road
Benton Harbor, Michigan 49022

Dear Gale:

Enclosed you will find the semi-annual report on the Whirlpool-sponsored home appliance robot project. We did not submit the first quarterly report because of the visit of yourself and other members of the Whirlpool staff in September to see the accomplishments of the project at that time. In addition to a detailed write-up, I am enclosing a videotape of the Heath Hero Robot navigating the perimeter of a large conference table. The work performed in accomplishing this is the subject of the attached report.

During the next quarter we envision closer examination of techniques for surface navigation as well as obstacle avoidance. We are considering the possibility of incorporating a teaching mode to cover a prescribed area along with appropriate obstacle avoidance sensors. This approach may lead to more rapid and more economical initial results which could later be modified.

On a more personal note, my initial cataract surgery has gone exceptionally well. Let me wish you, Al, Sam and the rest of my acquaintances at Whirlpool a Happy Holiday Season. Please continue to provide us with any material which you see that will be of assistance on the project. With best personal regards, I am

Sincerely yours,

Albert P. Sheppard
Associate Vice President
for Research

APS:lt
Enclosure

bcc: Pat Heitmuller

INTRODUCTION

Whirlpool Home Appliance Robot Research

June -- December, 1984

The home appliance robot research project was initiated with the initial objective -- as agreed on in joint meetings between Whirlpool and Georgia Tech staff -- to have the robot navigate a given area and avoid obstacles that would be potentially damaged by the robot or damaging to the robot. Described below is the approach that has been taken to accomplish this as well as the results that have been obtained to date. Accompanying the report is a standard VHS videotape which demonstrates the robot successfully navigating the perimeter of a large conference table.

The focus of the research thus far has been two-fold using the Heath Hero 1.0 Robot as the vehicle for demonstrating the above objective in a simple and economical fashion. Firstly, extensive research into sensors has led to a sonar-based edge-detection scheme which is designed to make the robot outline the perimeter of a platform by tracking its edge. This design scheme is being upgraded so that it will travel the perimeter of a room as well as traverse the interior regions.

Secondly, to make programming the Hero 1.0 Robot easier for the user, the IBM PC has been interfaced with it. All programs can be written with a text editor on the PC and then downloaded to the robot. Without this interface, all programs would have to be entered into memory using a hexadecimal keypad, making editing very tedious and difficult because the data in memory can only be displayed one byte at a time. This approach enables correctly working programs to be saved on a disk in the PC. The PC can read memory from the robot and write the data to a disk file for storage. This provides a way to save many programs without using all of the memory space on the robot.

The interface circuitry involved to implement writing to the robot requires two 8-bit bidirectional parallel ports in the PC and a matrix of tri-state buffers on the robot and a multiplexer. The circuitry on the robot simulates a keypress on the keypad. The monitor in the robot constantly polls the keyboard to check for a pressed key, so in order to simulate a keypress, a tri-state buffer is enabled which shorts the key momentarily. When the PC transmits a number between 0 and 15, corresponding to the hex digits 0 thru F, the multiplexer enables the tri-state corresponding to the number sent. Implementing the read from the robot circuitry involves using tri-state buffers connected to the seven-segment displays used to display the contents of a memory location. The IBM PC reads which segments of the display are "on" using a parallel port. Each digit gives a unique sequence of segments being turned on so that when the segments are read, the PC can decode the sequence of segments and determine which digit is being displayed. This data can then be written to a disk file for storage or editing.

The sonar-based edge-detection scheme gives the Heath Robot the capability of detecting the edge of a platform on which it is travelling, and thus prevents itself from falling off. The robot tracks the edge and eventually travels along the entire perimeter of the platform.

The method for achieving this is in two stages: (1) sensing the edge and (2) tracking the edge. Stage 1 required the development of a sensor system that detects the edge of the platform. After researching a variety of sensors, it was found that the Polaroid Ultrasonic Sensors were best suited for the task. These sensors emit an ultrasonic pulse train of approximately one millisecond in length. The pulses bounce off any obstacles in their path, and the echoes return to the sensors which are now in receive mode, acting like a microphone and thus indicate an obstruction. If the echoes have not been received within a precalculated time period, then the sensor has not detected the platform and hence is beyond the edge. All sensors, in normal mode, are supposed to detect the platform except for one sensor which is placed on the robot so that it "sees" beyond the edge. This is to keep the robot from deviating into the middle of the platform. The algorithm for this will, of course, be altered as an entire room is traversed by the robot as will be discussed below.

Stage 2 involved interfacing the signals obtained from the suitably positioned sensors with the robot's microprocessor, the MC6808. The signals are processed in such a way as to let the robot know whether or not it had deviated from the edge. In this way the robot knows if it needs to correct for a deviation or to continue on its previous course along the edge.

The advanced version of the aforementioned edge-detection system will enable the robot to cover the entire floor of a room. To achieve this, two modes of operation will be employed.

The first mode will require the robot to track the wall as well as keep itself a certain distance from it. This distance will depend on how far along the robot is in its routine. In order to track the wall, two sensors have been placed on the side of the robot; one toward the front and one toward the back. The distance from the back sensor to the wall is subtracted from the distance of the front sensor to the wall. The result is proportional to the angle that the robot makes with the wall. Keeping the difference of these two distances equal to zero (i.e. the front and back of the robot are the same distance from the wall) will make the robot travel parallel to the wall. Having the robot travel at the desired distance from the wall is a simple matter of comparing the robot's distance from the wall to the desired distance and adjusting accordingly.

The second mode of operation involves making the robot know how and when to cover the interior sections of the room. The method to be used involves the robot travelling along a rectangular path approximately half the width of the room with the same length (for now it assumed that the room is rectangular in floor plan). One side of the path will start out along a long-dimensioned wall, directing the robot to track that wall. The opposite side of the path will direct the robot to travel up the middle of the room. After travelling down the long wall, over to the middle of the short wall and up the middle of the room, the robot will come back toward the original wall but will track the wall a little farther away than the first time. When it reaches the middle of the room again it will go a little farther before turning to travel up that region of the room. This rectangular path will shift toward the other long-dimensioned wall every time the robot completes a rectangle. When the robot finally travels alongside this other wall it will have covered the entire floor of the room. The design for this mode of operation is very close to completion at which time the system will be tested as a whole.

The next stage of development will be investigation of the obstacle avoidance system which will be integrated with the floor-traversing system. Difficulties encountered with the present methodology are backlash in the relatively primitive wheel/gear/motor system of the Hero 1.0, surface slippage, and slowness of the algorithm with the given mechanical system. These indicate the need for additional work as well as investigation of the strengths and weaknesses of a command mode system where part of the traverse is taught and part is done on a collision avoidance basis. There is also some merit in establishing an interactive robot external room reference point for guidance of the system. These alternatives, along with the above-described extensions will be further evaluated during the next quarter.

WHIRLPOOL HOME APPLIANCE ROBOT RESEARCH
ANNUAL STATUS REPORT
July, 1984 -- June, 1985

by
Albert P. Sheppard, Brett Lapin and Thomas Single
Office of Vice President for Research
Georgia Institute of Technology
Atlanta, Georgia 30332

Introduction

The purpose of this project has been to develop background and understanding of the problems and requirements associated with the concept of a home appliance robot. While ideally such a device might be imagined to perform virtually every household function from cleaning to babysitting, it was agreed that the most likely initial application would be in the area of floor care. If the problems attendant to a mobile robotic floor care device can be solved, then it is reasonable to believe that much of the technology acquired could be readily extended to have the robot perform other tasks which would enhance its value to the consumer.

Initially, an assessment was done of existing personal robots which were largely hobbyist curiosities. The most popular and economical of multifunction personal robots was the Heath Hero 1.0. This robot was purchased and thoroughly evaluated in a strenuous laboratory environment. Significant problems were noted in the areas of repeatability and obstacle sizeing. After extensive meetings with Whirlpool staff, it was decided to pursue these two areas during this initial year of the project. Without question, the Polaroid ultrasonic sensors are the most precise economical sensors available on the market today. These were incorporated into the Hero but the problem of repeatability remained. With the accumulation of background informationd, it was decided to mount a two-fold approach to developing a reliable mobile robot: (1) refinement and enhancement of obstacle and path sensing using the ultrasonic sensors and (2) development of a rugged precision mobile robot platform which performed in a highly repeatable mode using the teach/repeat instruction characteristic of most fixed robots. Described herein are the results of these efforts which provide a solid basis for integration into a demonstration unit which should be able to navigate a reasonably sized plane and avoid obstacles of the size typically found in a home environment. With the anticipated proposed continuation, it is believed this is a reasonable goal for the July 1985-June 1986 time frame.

Mobile Robot
Area Navigation and Obstacle Avoidance

The Hero robot had to be altered in order to yield a more accurate form of steering. To this end, a potentiometer was added to the steering wheel giving continuous voltage measurements depending on the position of the wheel. This steering potentiometer enables the robot to be guided more accurately than its original system and gives continuous position measurements (analog) thereby minimizing execution time.

The design centers on an Intel 8748 single-chip microcomputer which acts as the "brain" of the robot's sensor-based control system. The 8748 calculates and manipulates distances obtained with the aid of the ultrasonic sensors and this, in turn, provides output signals for robot guidance. This means the robot can be guided from two possible sources: (1) the robot's own microprocessor, the MC6808, and (2) the sensor system's microcomputer, Intel's 8748. This fact points out a major consideration--interfacing the sensor system with the robot. This interface occurs in 2 places--there is the above-mentioned link to the steering wheel, and there is a direct link between the two microprocessors (to acknowledge data received or transmitted, processes needing to be started or completed, etc.).

In order to track the perimeter of a room the robot needs to know its orientation with respect to the wall it is currently tracking almost continuously. The orientation algorithm is based on two sensors spaced twelve inches apart on one side of the robot (sensors will be on both sides of the robot for bidirectional orientation in the updated system.) The current system deals only with unidirectional orientation, that is, side sensors are located on the left side of the robot.

The orientation algorithm takes input from the side sensors and outputs a voltage which is proportional to the angle the robot makes with the wall. The method for obtaining this angle is as follows: the distance from the back sensor to the wall is subtracted from the distance of the front sensor to the wall, giving a result that is proportional to the needed angle. In order to keep itself from deviating off course, the robot tries to keep this angle approximately equal to zero which keeps the robot travelling parallel to the wall.

However, if this were the only condition for corrective maneuvers, then the robot could not keep itself a desired fixed distance from the wall. Hence, another term had to be introduced into the orientation algorithm. This term represents the difference between the desired distance and the distance from the front sensor to the wall. Keeping this term approximately equal to zero keeps the robot at the desired distance from the wall. Because this algorithm is completely sensor dependent, the 8748 is responsible for the calculations.

While the above algorithm enables the robot to track a continuous section of a wall, a separate sub-algorithm must be used to enable the robot to negotiate a corner. A complication arises when it is noted that a corner may not always consist of 90 degrees. For this reason the side sensors dictate when the robot must stop turning, that is, when the sensors indicate the robot is approximately parallel to the adjoining wall. Hence, the order of operation of this sub-algorithm is as follows: when the front sensor "sees" that a wall is too close to the front of the robot, it interrupts all operations both in the MC6808 and the 8748 which in turn stops robot motion, the steering wheel is turned 90 degrees to the right (the wall is always on the left) after which the robot begins its turn; the 8748 stops the turn when appropriate, and tells the MC6808 that the turn is over, at which point the wheel is straightened out and the orientation algorithm is initiated once again.

The system design calls for continuous movement on the part of the robot except when a corner is encountered. At this point the robot will stop, turn appropriately, and return to continuous motion. In order to keep the robot almost continuously moving, the direction of motion is updated 10 to 15 times every second. This equates to approximately one update per inch of robot motion.

Using the above theory, the robot is able to navigate around the perimeter of a room.

In the future, this design will be expanded to produce a room-covering system which will enable the robot to track the perimeter of a room as well as traverse the interior regions so that when it has finished, the robot will have covered the entire room. The expansion will involve additions to both hardware and software. The hardware simply requires the addition of an ultrasonic sensor to the rear of the robot. However, the software changes are much more complex, requiring major additions to both the driver program in the robot's MC6808 and the control program in the 8748.

Once the room-covering system has been completed, an obstacle avoidance algorithm will be developed and integrated into the design yielding the overall system known as the Area Navigation System (ANS). Of major concern for the obstacle avoidance algorithm is the detection and displacement calculations of an obstacle. That is, an irregularly shaped (thin) object, such as a chair leg or table leg, must not only be detected, but the robot must also know its orientation (direction and distance). As such, a more sophisticated sensor system must be incorporated into the design, possibly even a vision system. Using this sensor system, the robot must calculate both the best path around the obstacle and the best new path beyond the obstacle to its destination.

Overall, the primary concern of the ANS is having the robot know its own global orientation as well as its local orientation. In other words, the robot must know where it is in its absolute frame of reference which is the largest area in which the robot is constrained to work, in this case most likely a house. The robot also needs a much more detailed picture of its local surroundings, in this case most likely a room. This is where the sensor system will contribute its maximum capabilities. Hence, the robot will keep a local picture so that it can maneuver in a room, regardless of any obstacles in its path, and it will also keep a global picture so that it will know where to go and how to get there throughout the house.

Mobile Robot

Teach-Mode and Precision Direction

After working with a Heath Hero 1.0 robot, it was clear that in order to design a navigation system for a robot, a very accurate vehicle was needed. Therefore, a precision mobile robot vehicle was designed and constructed. The vehicle is large enough to accommodate many peripherals, which may be added to it in the future, although to this date, the drive and steering mechanisms have been the principal focus.

The vehicle is controlled by an IBM-PC which is mounted on the mobile robot which uses a three-wheel design. The computer is interfaced to the robot via parallel ports. The robot has two motors--one of which controls the front drive and the other controls the steering also on the front wheel. The two rear wheels are free. There are two modes of operation for the vehicle: teach and repeat. A teach pendant is used to teach the vehicle a pattern to follow while in teach-mode. When the vehicle is in the repeat mode, it will repeat the pattern that it was taught. Thus, it can be programmed to navigate through a room, avoiding fixed obstacles.

In order to fulfill the design requirements, two different motor control circuits had to be designed, one for the drive motor and encoder, and another for the steering motor and encoder. The encoders are used for feedback from the motors to keep track of distance travelled and angular change. The motors also have tachometers that can be used in the future for motor speed control.

Software was written to control the vehicle. The software reads and writes to several parallel ports on the IBM-PC. These ports are interfaced to circuit boards on the vehicle that control the motors. As with any teach-mode robot, it is important that the vehicle be started from the exact position reference used in the teach-mode prior to initiation of the repeat-mode. If this is done, the robot can repeat the pattern very accurately. Further work is required to establish the repeatability of this position because the mobile robot is somewhat different from a fixed robot system.

The vehicle control scheme works in the following manner. While in the teach mode, the computer constantly reads the teach pendant for a command. Once a command is received, the computer deciphers that command and sends the appropriate signals, (i.e. direction, steering enable, drive enable, etc.), to the control boards on the vehicle. The desired motor (steering and/or drive) begins moving until a new command is received from the teach pendant. At this time, the computer disables the motor, reads the encoder counters and stores this data in an array. It then reads the next command from the teach pendant and again executes it in the same manner. As noted, once the user has completed the teach procedure, the robot must be placed precisely back in the original starting position. It then waits for the repeat command from the teach pendant. When the command is issued, the computer reads the data in the array and sends the data to comparators on the control circuit. It then enables the motor to start and the comparators compare the encoder counters with the data sent by the computer. When the two numbers being compared are the same, the circuit disables the motor and sends an acknowledge signal to the computer. When the computer receives this signal, it reads the next command from the array and again sends the data to the circuit and enables the motor. It repeats this procedure until the entire pattern has been repeated.

The vehicle is constructed out of aluminum. It is 21-1/4 inches wide and 16 inches long. The estimated weight of the vehicle is 60 pounds. This makes the vehicle large enough to carry any peripherals that will be added in the future, including a small vacuum cleaner. The motors that are used are DC servo motors with optical encoders on them. Several high-density batteries are used to supply the power to the power supply board which powers the computer, drive circuits, teach pendant, and motors.

In order to improve the accuracy of the vehicle, the repeatability must be tested over different paths. Once this is tested, the software can be altered to correct for slippage and other errors that may occur during the teach or repeat modes. After the repeatability has been tested and improved, if necessary, sensors will be added in order to enhance the navigation capabilities of the robot.

Certain hardware additions will be made, such as a small LCD display panel to display the user menus. Also, the teach pendant will be expanded to include a hex-keypad so the user can enter commands more easily without having to use the computer keyboard.

A voice recognition system could be added to the robot so that it would be able to accept voice commands rather than just receiving commands from the teach pendant. This feature could be used as a safety feature so that a stop command could be issued without having to touch the robot.

The software will also be altered to allow different options for the user. The software will be able to store the array of commands in a disk file, so that the user will not have to teach the robot the same pattern every time he wants the robot to repeat the pattern. Ultimately, the user should also have the option of inputting the desired end position of the robot and the locations of all obstacles between the original position and the desired position, and the robot would calculate the shortest path without running into any obstacles. The system should use a global coordinate system so that the robot will always know where it is within this coordinate system.

Exhibit B

WHIRLPOOL HOME APPLIANCE ROBOT RESEARCH
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In order to fulfill the design requirements, two different motor control circuits had to be designed, one for the drive motor and encoder, and another for the steering motor and encoder. The encoders are used for feedback from the motors to keep track of distance travelled and angular change. The motors also have tachometers that can be used in the future for motor speed control.

Software was written to control the vehicle. The software reads and writes to several parallel ports on the IBM-PC. These ports are interfaced to circuit boards on the vehicle that control the motors. As with any teach-mode robot, it is important that the vehicle be started from the exact position reference used in the teach-mode prior to initiation of the repeat-mode. If this is done, the robot can repeat the pattern very accurately. Further work is required to establish the repeatability of this position because the mobile robot is somewhat different from a fixed robot system.

The vehicle control scheme works in the following manner. While in the teach mode, the computer constantly reads the teach pendant for a command. Once a command is received, the computer deciphers that command and sends the appropriate signals, (i.e. direction, steering enable, drive enable, etc.), to the control boards on the vehicle. The desired motor (steering and/or drive) begins moving until a new command is received from the teach pendant. At this time, the computer disables the motor, reads the encoder counters and stores this data in an array. It then reads the next command from the teach pendant and again executes it in the same manner. As noted, once the user has completed the teach procedure, the robot must be placed precisely back in the original starting position. It then waits for the repeat command from the teach pendant. When the command is issued, the computer reads the data in the array and sends the data to comparators on the control circuit. It then enables the motor to start and the comparators compare the encoder counters with the data sent by the computer. When the two numbers being compared are the same, the circuit disables the motor and sends an acknowledge signal to the computer. When the computer receives this signal, it reads the next command from the array and again sends the data to the circuit and enables the motor. It repeats this procedure until the entire pattern has been repeated.

The vehicle is constructed out of aluminum. It is 21-1/4 inches wide and 16 inches long. The estimated weight of the vehicle is 60 pounds. This makes the vehicle large enough to carry any peripherals that will be added in the future, including a small vacuum cleaner. The motors that are used are DC servo motors with optical encoders on them. Several high-density batteries are used to supply the power to the power supply board which powers the computer, drive circuits, teach pendant, and motors.

In order to improve the accuracy of the vehicle, the repeatability must be tested over different paths. Once this is tested, the software can be altered to correct for slippage and other errors that may occur during the teach or repeat modes. After the repeatability has been tested and improved, if necessary, sensors will be added in order to enhance the navigation capabilities of the robot.

Certain hardware additions will be made, such as a small LCD display panel to display the user menus. Also, the teach pendant will be expanded to include a hex-keypad so the user can enter commands more easily without having to use the computer keyboard.

A voice recognition system could be added to the robot so that it would be able to accept voice commands rather than just receiving commands from the teach pendant. This feature could be used as a safety feature so that a stop command could be issued without having to touch the robot.

The software will also be altered to allow different options for the user. The software will be able to store the array of commands in a disk file, so that the user will not have to teach the robot the same pattern every time he wants the robot to repeat the pattern. Ultimately, the user should also have the option of inputting the desired end position of the robot and the locations of all obstacles between the original position and the desired position, and the robot would calculate the shortest path without running into any obstacles. The system should use a global coordinate system so that the robot will always know where it is within this coordinate system.